Introducing Structural Considerations into ATC Complexity Metrics

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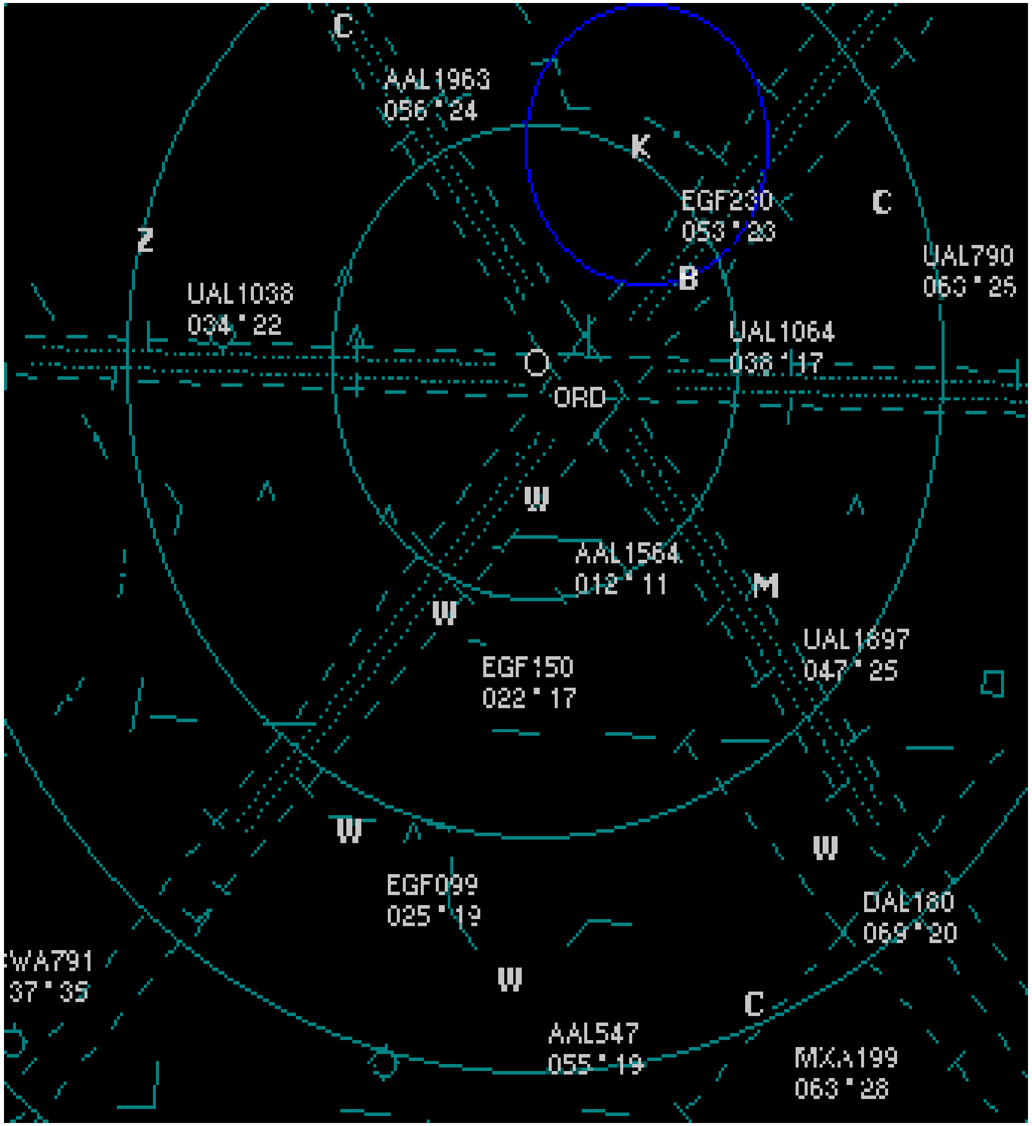


Introduction

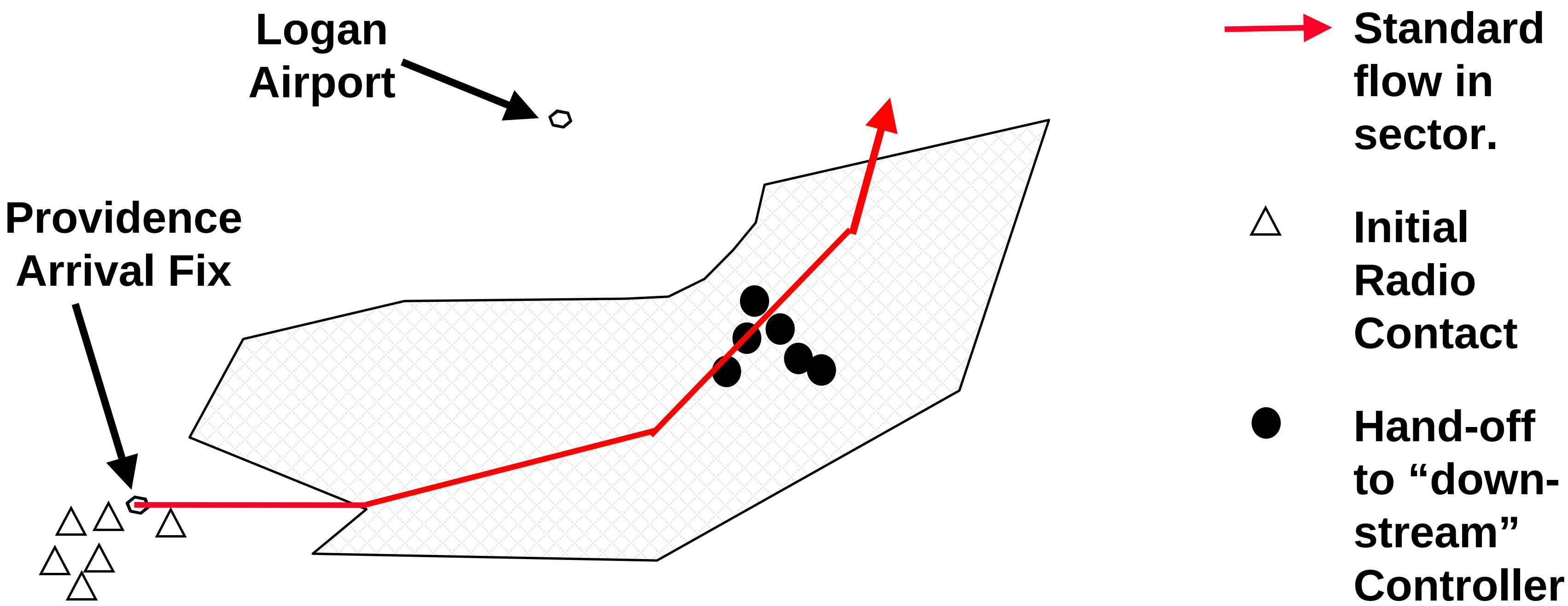
- **Project Goal**
  - ❑ Develop operationally useful measures of complexity.
- **Why study complexity?**
  - ❑ Cognitive challenge of ATC is one of the fundamental limits that restricts the capacity of a piece of airspace.
  - ❑ Previous research has concentrated on measures of that cognitive challenge in the Free Flight environment.
    - ◆ E.g. “Dynamic Density”
  - ❑ However, these measures do not take into account the inherent structure present in the current operational environment.
- **Incorporating structure would:**
  - ❑ Increase the sophistication of predictions of potential controller overload situations (E.g. Monitor Alert in ETMS).
  - ❑ Provide guidance to airspace redesign projects.

Approach

- **Collaborative effort, sponsored by FAA, with partners at Centre d'Etudes de la Navigation Aérienne (CENA) in France.**
- **Step 1 - Literature Review**
  - ❑ Current metrics
    - ◆ Simple count of Number of Aircraft in a Sector
  - ❑ Previously proposed metrics
    - ◆ NASA’s Dynamic density, Wyndemere Corporation
- **Step 2 - Field Observations**
  - ❑ Case study at Boston TRACON
    - ◆ Comparison of sectors – what makes one harder than another?
  - ❑ Parallel observations made by partners in France
  - ❑ Generated preliminary list of key factors in complexity.
- **Step 3 - Proposing metrics**
  - ❑ Three methodologies being followed.
  - ❑ Collaboration provides feedback mechanism, allows each group’s findings to complement / be incorporated in other group’s work.
- **Step 4 - Validating those metrics**

Observation: The physical definition of a sector is not always appropriate.

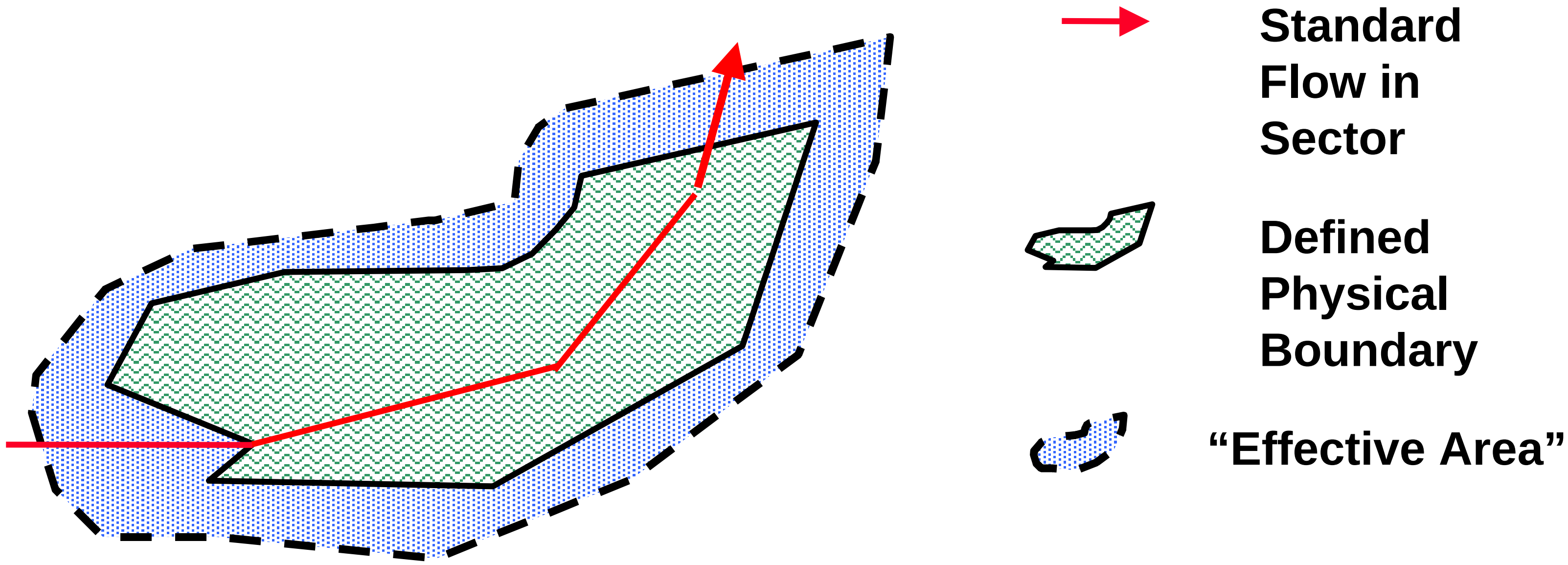
- **The airspace considered by a controller appears to be shifted "up-stream" from the "physical definition."**
  - ❑ Example: Plymouth sector in Boston TRACON:



Graphic Courtesy Aaron Karlson, Training Department, Boston TRACON, FAA.

Observation: The physical definition of a sector is not always appropriate.

- **Identified concept of "Effective Area" of a sector**
  - ❑ Example: Plymouth Position in Boston TRACON:



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Created Preliminary List of Key Factors in Complexity

- **The factors identified in the literature review and through observation have been grouped into three categories:**
  - <u>Structural Factors</u>
    Factors that reflect the underlying structural properties of the airspace.
    - Airspace Properties
    - Standard Flow Structures
  - <u>Aircraft Distribution Factors</u>
    Factors that are dependent on the dynamic positions and velocities of aircraft in the airspace.
    - Density Factors
    - Encounter Factors
    - Characteristics of the Aircraft in the Airspace.
  - <u>Operations Factors</u>
    Factors affecting the operating procedures in the airspace.
    - Operational Constraints
    - Co-ordination / Communication Issues

Structural Factors

Factors that reflect the underlying structural properties of the region of airspace.

- **Airspace Properties**
  Factors related to the static geometric properties of the region of airspace.
  - ❑ Sector size.
    The total airspace nominally available for use by the controller.
  - ❑ A sector's "Effective Area"
    Events / factors outside the immediate airspace the controller is responsible for impact the complexity of a situation.
  - ❑ Sector shape and the presence of shelves.
    Shelves are small blocks of airspace, of a limited altitude range, around the sector boundary.
  - ❑ Altitude levels available.
    The number of discrete altitude levels that a controller, using solely vertical separation criteria, could assign to aircraft within the airspace.
  - ❑ Spatial distribution of airways / jet-routes.
    How the airways are laid out within the airspace? How densely packed are the airways? How many intersections between airways?

- **Standard Flow Structures**
  Factors describing the standard flight paths, e.g. "flows," of aircraft within the airspace.
  - ❑ Number, strength, directional distribution of standard flows.
    How many flows in the sector? How many aircraft are typically in each flow? How many directions do the flows represent? How are the flows aligned in the airspace?
  - ❑ Intra-flow properties:
    How complicated is the trajectory of the flow? Are there multiple turns, altitude changes?
  - ❑ Inter-flow relationships:
    If there exist multiple flows in the airspace, how do they interact with each other? Are there lateral crossings? Intersection points? "Merge points" where two flows join together?

Aircraft Distribution Factors

Factors that are dependent on the dynamic positions and velocities of aircraft in the airspace.

- **Density Factors**
  Factors related to the density of aircraft in the airspace.
  - ❑ Number of aircraft.
  - ❑ Local traffic density.
    A factor to capture any localized concentrations of aircraft. Specifically, to capture situations such as “piggy-backs” where two aircraft enter a sector with only altitude separation. Comments from controllers indicated this can make a sector more complex. Must be considered “upstream” of the definition of the physical boundary of the sector.

- **Encounter Factors**
  Factors related to inter-aircraft relationships, e.g. encounters or potential conflicts.
  - ❑ Spatial geometry of encounters.
    The relative angles, speeds, distance of closest approach, of any two or more aircraft within the airspace. Also included is consideration of the difficulty in solving any encounter (e.g. two aircraft being within 10 miles of each other may simply be following each other in trail as opposed to the greater complexity represented by two aircraft being on converging courses).
  - ❑ Location of an encounter.
    How close is an encounter to the boundary of the airspace? Are there other constraints on how the controller could react to the encounter?
  - ❑ Time duration of an encounter.
    How long does the encounter last?

Aircraft Distribution Factors

Factors that are dependent on the dynamic positions and velocities of aircraft in the airspace.

- **Characteristics of Aircraft in the Airspace**
  Factors related to the properties of aircraft within the airspace.
  - ❑ Aircraft performance.
    Differences in aircraft type (heavy jets vs. Cessnas) and pilot proficiency (ATP vs. student pilot) will produce a range in the performance characteristics of aircraft within the airspace (i.e. climb rates, turn rates etc…). Both the range of characteristics and the capability of individual aircraft are important.
  - ❑ Aircraft speeds.
    The range of aircraft speeds within the airspace. Observations indicate that the importance of this factor scales with sector transit time: in a small sector, speed differentials are not as difficult to handle as in a larger sector.
  - ❑ Altitude levels occupied.
    The range of altitude levels occupied by aircraft within the airspace. This factor is a measure of how much of the controller's altitude "resources" are available.
  - ❑ Number of aircraft in transition.
    The number of aircraft changing their trajectory through turns, altitude changes, or speed adjustments.
  - ❑ Sector transit time.
    The time an individual aircraft spends within the sector boundaries.

Operations Factors

Factors capturing the effects of the operating procedures used in the airspace.

- **Operational Constraints**
  Factors that impact the operational flexibility available to the controller.
  - ❑ Available airspace:
    The airspace that a controller has available can be restricted by operational constraints such as: weather, especially the presence of thunder-storms, the availability of special-use or restricted airspace, and the availability and current use of airspace designated for holding activities. This factor also reflects the ability of the controller to "buffer" aircraft, e.g. cope with the sudden inability to hand-off aircraft "down-stream."
  - ❑ Procedural restrictions:
    The flexibility of the controller can also be restricted by the presence of procedural restrictions such as noise abatement procedures, and the requirement to meet traffic management restrictions such as miles-in-trail spacing.

- **Co-ordination / Communication Issues**
  Factors capturing how coordination and communication operational procedures can impact the complexity of the airspace.
  - ❑ Point-outs
    Point-outs occur when a controller co-ordinates with adjacent controllers to 'borrow' some airspace for a temporary period of time. Complexity factors include how often point-outs occur, and how many controllers coordination is required with.
  - ❑ Handoffs.
    Transferring control of an aircraft to or from adjacent controllers.
  - ❑ Frequency congestion:
    The complexity of a piece of airspace will be influenced by the number of instructions a controller is trying to give, particularly when this number exceeds the capacity of the radio communications system.

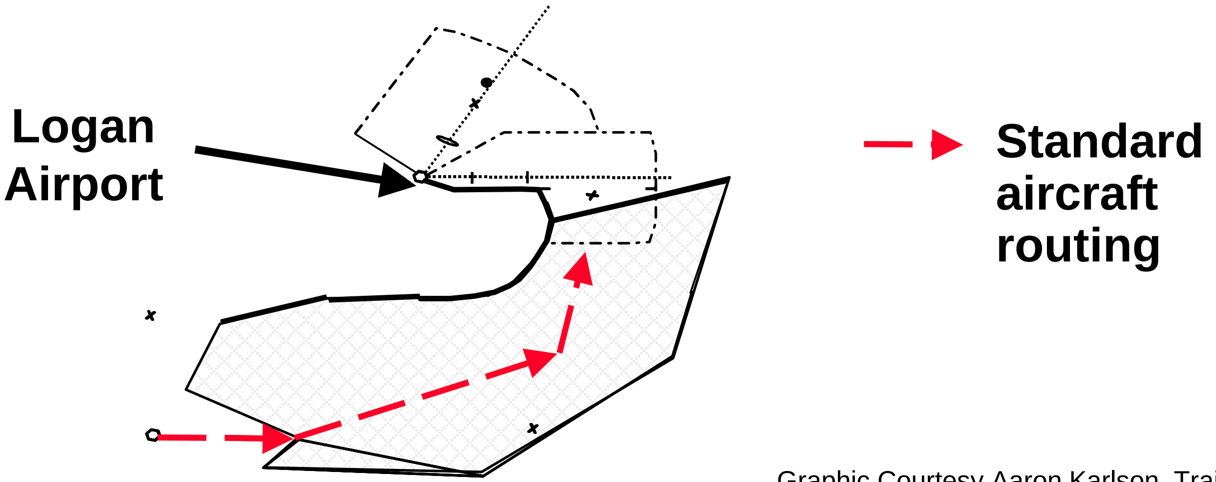
Preliminary Complexity Metric Considerations

- **A complexity metric should capture these general principles:**
  - ❑ The “Load” represented by the current traffic distribution.
  - ❑ The underlying organization of the airspace:
    - ◆ E.g. “order” in how the traffic distribution is organized.
  - ❑ The regularity / predictability of the situation.
  - ❑ The flexibility / controllability available to the controller.
- **A metric should produce “linguistically meaningful” outputs**
  - ❑ Validation:
    - ◆ Controllers rate ATC situations consistently when using broad “linguistically meaningful” discrete categories.
      - ➪ E.g. “Low”, “Medium”, “High” levels of complexity.
    - ◆ These ratings provide a “golden” standard to validate a proposed metric against.
  - ❑ Implications for metric development:
    - ◆ Investigate alternate formulations to standard weighted equation.

Current Work: Modelling Controller Process

- ⇒ **MIT – Modelling Controller Process**
- **CENA – “Microscopic” / Clusters Analysis**
- **Joint – Classification Schemes**

- **Provide a theoretical framework to assess relative importance of previously identified factors.**
- **Preliminary hypothesis - Controllers operate in one of two modes of operation:**
  1) Initial contact with an aircraft
     - Evaluate how this aircraft fits into the plan for the sector.
     - Identify and schedule any necessary actions.
  2) As situation evolves
     - Monitor overall conformance to plan.
     - Assess need to adjust plan.



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Current Work: Modelling Controller Process

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- **Propose a metric based on a formal breakdown of the problem into the effects of:**
  - ❑ Structure
  - ❑ Traffic Load
  - ❑ Operations
- **Tentative formulation:**

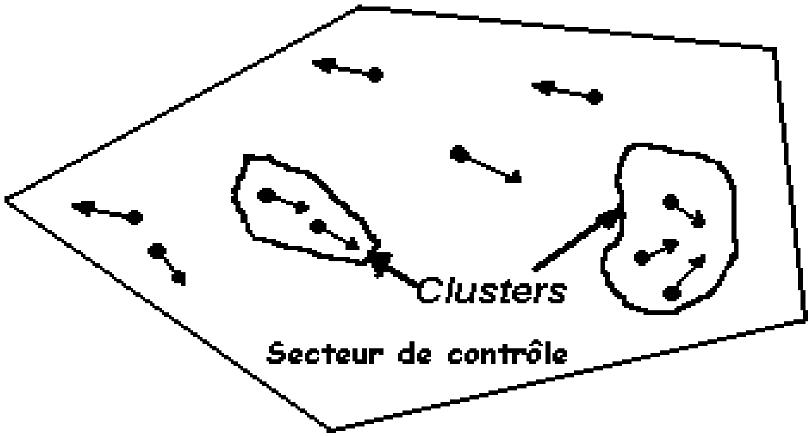
$$Complexity = \langle Structure \rangle \otimes \langle Traffic\ Load \rangle \oplus \langle Operations \rangle$$

where ⊗, ⊕ are "to be determined" operators.

Current Work: “Microscopic” / Clusters Analysis

- MIT – Modelling Controller Process
- ⇒ **CENA – “Microscopic” / Clusters Analysis**
- Joint – Classification Schemes

- **Use the current traffic distribution as the sole input into the metric.**
  - ❑ E.g. relative distances, relative speeds between aircraft
- **Introduce concept of a “cluster” of aircraft.**
  - ❑ A “cluster” is a group of aircraft in close proximity within the sector.
  - ❑ Perform analysis on both intra- and inter- cluster components.
  - ❑ Include previously identified structural factors in this analysis based only on the aircraft distribution.



Current Work: Classification Schemes

- **MIT – Modelling Controller Process**
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- **Producing "Linguistically Meaningful" Outputs**

Support Vector Machines

- ❑ Map a set of training points in a parameter space into discrete, "linguistically meaningful" levels.
- ❑ Important properties:
  - ◆ Creates non-linear boundaries between levels
  - ◆ Able to tolerate "fuzzy" boundaries
- ❑ Applications
  - ◆ Can be used to identify which parameters account for variations in the complexity